USNRDL-TR-557

Copy 128
23 March 1962

RESIDUAL CONTAMINATION OF QUARTERMASTER CORPS CLOTHING AND PACKAGING MATERIALS

RETENTION OF SIMULATED DRY FALLOUT PARTICLES

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ADMINISTRATIVE INFORMATION

The work reported was part of a project sponsored by the U.S. Army Quartermaster Corps. The project is described in this Laboratory's USNRDL Technical Program for Fiscal Years 1960 and 1961, Revision #2, 1 November 1959, where it is designated Program B-3, Problem 4.

ACKNOWLEDGMENT

Appreciation is expressed to J.T. Quan and J.D. O'Connor for their generous assistance during this test.

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ABSTRACT

This study was conducted to determine the amount and size of simulated dry fallout particles retained by various Quartermaster Corps clothing and packaging materials, after field decontamination procedures are applied. An attempt also was made to correlate qualitatively the amount retained with surface properties of the materials.

Dry spherical, glass beads in selected size-distribution groups (14-270 μ, 14-100 μ, and 14-75 μ) were used to simulate fallout particles from a nuclear detonation. The amount remaining was measured gravimetrically and visually by optical microscope after application of three mechanical removal operations.

It was found that materials having entrapping fibers retained the largest amount of beads. The amount was directly proportional to the number of open spaces and the number of loose fibers that acted as entrappers. Scrim-back packaging material retained 0.3 g/ft^2 of particles which had an average diameter of 50 μ. Cotton sateen clothing and cotton poplin clothing had lesser amounts. All other materials tested retained zero or insignificant amounts.

Mechanical entrapment of particles by the loose fibers appeared to be the principal mechanism of retention.

SUMMARY

Problem

This study was conducted to measure the amount of glass beads, simulating dry fallout, that is retained by certain Quartermaster Corps clothing and packaging materials, and to qualitatively determine how the simulated beads were retained.

Findings

Mechanical entrapment of the macroscopic- and microscopic-sized spherical beads was the principal mechanism of retention. Materials having high amounts of entrapping fibers retain detectable amounts of these beads even after the application of three mechanical removal operations. All cloth and Scrim-back packaging material are in this category.

INTRODUCTION

Radioactive fallout particles large enough to be seen adhering to materials are deposited at the earth's surface after the violent disturbance of a nuclear detonation subsides. Material and personnel located within the fallout area present potential collecting surfaces to the descending particles.

Such potential radiological contamination takes on tactical military significance when the collecting surfaces of radioactive fallout particles are clothing worn by soldiers or material handled by them. Defense against the resultant hazards would consist in decontamination of the clothing and in minimizing the contaminability of the clothing and packaging materials. The contaminability-decontaminability characteristics of common materials remained to be determined.

An investigation[1] was conducted on foot soldiers crawling through an area contaminated with dry synthetic fallout material. Results of this test indicated that the soil loading on the soldier's clothing was 10 times that on their skin. Simultaneously, the QMC preliminarily evaluated the field laundering facilities for clothing contaminated with the same dry synthetic fallout material.

These two tests, however, did not involve the study of the mechanism of soil particle retention. This knowledge in relation to particle size range, is necessary for definitive evaluation of clothing decontamination methods. It was also desired to know whether microscopic-sized dry particles would be difficult to remove from packaging materials.

This investigation was conducted on a laboratory scale, to determine whether various QMC clothing and packaging materials would retain measurable quantities of 14-to-270-μ-sized particles and to qualitatively determine the method of retention.

CHARACTERISTICS OF FALLOUT FROM NUCLEAR DETONATIONS

Radioactive fallout particles are formed by the interaction of condensing vaporized materials: metals and fission products derived from the bomb and the associated bomb structure, some surface materials, with other surface materials that are swept up into the cooling fireball.

The physical properties of fallout particles depend upon many variables, such as height and size of detonation, bomb constituents, associated bomb structures, and nature of environmental materials. A study[2] of some of the physical and chemical properties of fallout collected at the Nevada Test Site and the Eniwetok Proving Grounds demonstrated the wide variation in the properties according to the detonation conditions. Collecting stations at various locations also produced evidences of the differences in the physical and chemical properties of the fallout particles.

Reference 2 described particles collected from a tower shot at Eniwetok Proving Ground. The most common type was black, spheroidal, weakly magnetic, and usually cracked and veined with calcium salts. These particles varied in size from about 1/4 to 1 mm in diameter. A second type was black, usually shiny with a metallic luster, spherical, and magnetic, and were found to be up to about 1/2 mm in diameter. A third type was small black spheres ranging from about 10 μ in diameter to submicroscopic.

The fallout particles collected following tower shots at Nevada were similar to the first type described above, black spheres ranging from 1 or 2 mm to about 1/4 mm in diameter. They had a metallic or glossy luster and many were magnetic. The densities of the several that were measured varied from 1.38 to 2.56 g/cc.

The fallout particles from the Eniwetok and Bikini surface shots were of two shapes, angular and spherical, both derived from coral sand grains. These particles were white to pale yellow or gray, and varied from 1 or 2 mm to several microns in diameter. The densities varied from 2.0 to 2.8 g/cc.

Fallout particles collected following a low-yield surface shot in Nevada consisted of glass derived from the melting and subsequent fusion of the silicate minerals in the soil. There were two types: transparent spheres of a yellow-green color; and irregular, opaque, brown grains which did not appear different from the unaltered mineral grains of the original soil. Both types were found to be up to 2 or 3 mm in diameter.

Simulation of fallout particles from all types of nuclear detonation was unnecessary for the scope of this test. If a foot soldier encounters fallout of visible size range, it probably would have come from a surface or low air burst over land areas. According to the results obtained from surface, tower, and low air detonations over Nevada Test Site, the particulate matter would be dry, of various shapes, and have a density close to that of glass. Therefore, dry, glass spheres, of 2.5 g/cm^3 density and in three size ranges, were used for the tests.

INTERACTION OF PARTICLES WITH MATERIALS

Contamination

Physical contamination by microscopic radioactive fallout particles of materials used by the Quartermaster Corps for clothing and packaging is similar in mechanism to the soilage of fabrics by dust particles. Getchell, in a study[3] on fabrics soiled by dust particles, determined impingement and retention as separate phases in the soilage.

Furthermore, he considered retention as a function of the material and impingement as a function of the field condition. The mechanisms of impingement are: (1) diffusion of very small particles in air; (2) deposition of medium- and large-sized particles from air; (3) direct transfer of particles from another soiled surface; (4) interception or contact by inertial effects of particles in a moving air stream; and (5) electrostatic attraction either from air or from another surface.

Two mechanisms which are most predominantly involved in the deposition of fallout particles on personnel or packaging materials in the field, were simulated in the present study. The two mechanisms are deposition and a variation of the direct transfer method of impingement. The deposition of medium and large particles from air would follow Stoke's Law for free-falling particles, and any unprotected surface can become contaminated by these falling particles. The direct transfer method is the transfer of particles from a soiled or contaminated surface or material to a clean surface or material by contact between the two surfaces.

The mechanisms of retention are: (1) mechanical occlusion; (2) oil bonding; and (3) electrostatic forces.

Decontamination

Decontamination of microscopic radioactive fallout particles from any surface is the physical removal of particles by overcoming the

forces of retention. The methods employed in decontaminating are (1) mechanical, (2) chemical, and (3) combination of mechanical and chemical means.

In the field, personnel exposed to visible fallout would employ three removal operations. They would, if no previous instructions were given, rise and seek shelter. Once under shelter, they would attempt to remove visible particles by brushing, and if possible, by applying a stream of air or other more vigorous method of particle removal. Up to this point, the personnel has performed three removal operations. By rising, he has removed particles which are acted upon by gravity. By brushing, a mechanical method has been employed to remove more particles. By applying air or other more vigorous mechanical methods, all particles that are likely to be removed have been displaced from the clothing. Field radiacs would be necessary to determine the need for further decontamination which could be accomplished through chemical decontamination.

These field methods were simulated in the laboratory test by sequentially (1) placing the contaminated sample in a vertical position; (2) brushing; and (3) applying an air stream over the sample. Size and amount of particles remaining after the laboratory test sequence were assumed to be indicative of the size and amount of particles remaining under field conditions.

The sequence was also utilized on the packaging materials, though packages would generally be left undisturbed until cessation of fallout, to standardize the test conditions.

EXPERIMENTAL PROCEDURES

MATERIALS TESTED

Nine clothing and 15 packaging materials supplied by the Quartermaster Corps* were studied:

Test Code	Material, as described by suppliers
Clothing	
C-1	Cloth, cotton, sateen, 9.0 oz. OG-107, untreated
C-2	Cloth, cotton, sateen, 9.0 oz. OG-107, fire-resistant treated
C-3	Cloth, cotton, sateen, 9.0 oz. OG-107, water-repellant treated
C-4	Cloth, cotton, sateen, 9.0 oz. OG-107, treated with experimental finish Q
C-5	Cloth, cotton, sateen, 9.0 oz. OG-107, treated with experimental finish QP
C-6	Cloth, cotton, sateen, 9.0 oz. OG-107, treated with experimental finish ET
C-7	Cloth, cotton/nylon, poplin, 7.0 oz. OG-107, untreated
C-8	Cloth, cotton, poplin, 5.0 oz. Khaki #1, untreated
C-9	Cloth, cotton, poplin, 5.0 oz. Khaki #1, fire-resistant, treated

*Further information on the materials tested may be obtained from: the Quartermaster Research and Engineering Center, Natick, Mass., on the clothing samples; from the Quartermaster Food and Container Institute for the Armed Forces, Chicago, Ill., on the packaging materials.

Test Code	Material, as described by suppliers
Packaging	
B-1	Laminated board face side - 1.5 mil clear polyethylene coating on 60 lb creped kraft paper ("X-crepe") back side - 1/10 inch hardboard ("Weytex")
B-2	Laminated board face side - 1.5 mil black polyethylene coating on 90 lb kraft paper ("Polykraft") back side - 1/10 inch hardboard ("Superwood")
B-3	Laminated board face side - 1 mil clear polyethylene coating on duplexed creped kraft paper reinforced with fiberglass scrim ("Thilcotuf") back side - 1/8 inch hardboard ("Armorboard")
B-4	Laminated board face side - 170 lb kraft with imbedded sisal reinforcing strands ("Cordex") back side - 1/8 inch hardboard ("Armorboard")
B-5	Laminated board face side - 170 lb kraft with imbedded sisal reinforcing strands ("Cordex") back side - 1/8 inch hardboard ("Superwood")
B-6	Laminated board face side - 60 lb kraft face duplexed to 114 lb W3C liner with 15 lb polyethylene back side - 1/8 inch hardboard ("Armorboard")
B-7	Laminated board face side - 190 lb kraft with imbedded sisal reinforcing strands back side - 3/16 inch hardboard ("Superwood")
B-8	Laminated board face side - 0.012 inch 3003 H24 Aluminum back side - 1/8 inch paper overlaid veneer
B-9	Laminated board face side - 0.012 inch 3003 H24 Aluminum back side - 3/16 inch paper overlaid veneer

Test Code	Material, as described by suppliers
Packaging (contd)	
B-10	Laminated board face side - 0.012 inch 3003 H24 Aluminum back side - 3/16 inch group 3 plywood, container grade
A-6	Corrugated cardboard, V3C
A-7	Solid cardboard, V2S
A-8	Solid cardboard, V3S
F-6	Flexible packaging material, Scrim-back (Fr2120)
F-7	Flexible packaging material, 3 lb polyester coating-0.001 foil-0.001 mylar

Cotton sateens were exposed on the side which showed the twill or diagonal lines under a microscope. Poplin cloth did not have a face-to-back difference so one side was arbitrarily selected and used consistently throughout the test, a small ink mark identifying the back side.

The face side of laminated boards were exposed. The cardboard material had printed matter on one side, so this side was selected. For the flexible materials, the 0.001 mylar and the rough surfaces of the Scrim-back were exposed to the glass beads.

To allow correlating particle retention with surface properties, the faces of the materials were microscopically examined. Two general categories were observed, smooth and fibrous. All packaging materials except Scrim-back were smooth, while all cloth samples and Scrim-back were fibrous.

The sample materials were cut into nominal 2 x 2-in. squares. This size was selected because of convenience in handling, and it was the maximum size the analytical balance could accommodate. All samples were handled carefully to minimize contamination by oil films. All materials were new and void of folds, creases, seams, or any visible debris. No special cleaning or other treatments were given prior to exposure.

SIMULATION OF FALLOUT PARTICLES

Dry, non-radioactive, glass beads* were used to simulate the fallout from a land surface or a low air burst over dry land. Although the size range of fallout particles are known to cover a much greater range, the size range for these tests was limited to 14 to 270 μ. Preliminary tests had indicated that beads larger than 270 μ were easily removable from clothing samples by field methods such as were being studied.

Sizing of particles

Three groups of beads (density 2.5 g/cm^3), each of different size distribution, were selected from the original supply* by sieving with 5 standard screens. One size group (designated 70M) was sieved to cover the range from 14 to 270 μ in diameter. The distribution was skewed with a model value of 200 μ. This group was used to determine the particle size predominantly retained by the various materials.

The other two size groups (designated 170M and 325M) had average bead diameters of 75 and 50 μ, respectively. The size distributions were approximately normal, and were obtained by sieving on a commercial sieving machine**. These groups were those retained on the 170- and 325-mesh standard screens.

The size distributions for the three groups are shown in Fig. 1. These distributions were determined by measuring bead diameters on enlarged photomicrographs taken of random samples for each size group. The calibration scale was devised by photomicrographing and enlarging, under similar conditions, a standard stage micrometer.

APPLICATION OF PARTICLES

To simulate the deposition mechanism of impingement, a particle distributor[4] was used to deposit the beads onto the material samples. It consisted of a slowly rotating (1 rpm), 8-in. diameter circular table, an air nozzle, funnel, and a square vertical column which had fourteen No. 8 size screens. The screens were located 1 in. apart and were used to deflect and distribute the beads uniformly over a 2 x 2-in. area. Weighed amounts of glass beads were dropped onto the outer edge of the rotating table through a funnel. As the table turned, the beads were blown off the table and into the square column. They dropped onto

* Flex-O-Lite 831 Reflective Glass Beads, Flex-O-Lite Corp., St. Louis, Missouri.

** W. S. Tyler Co., Cleveland, Ohio.

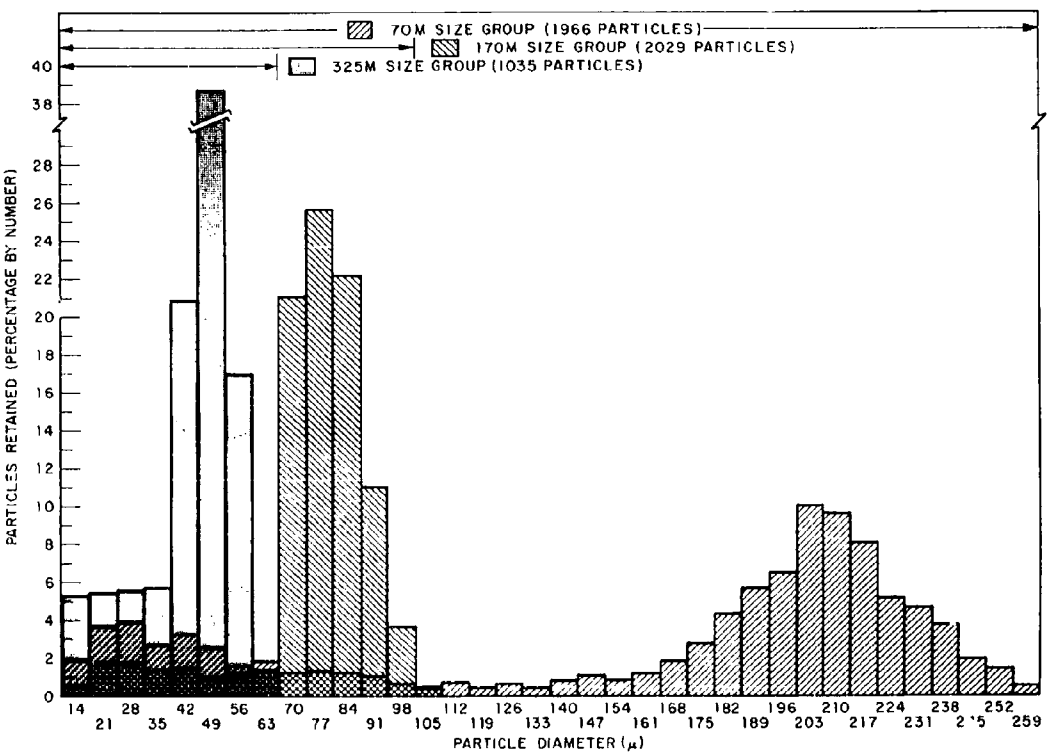

Fig. 1 Size Distribution of Three Particle-Size Groups.

the sample, which was located in a horizontal position 1/2 in. below the column opening. The samples were mounted in a recessed container to prevent lateral movement during the tests and to keep the sample flat.

To simulate the mechanism of impingement by direct transfer, by means of a rubber roller and a pressure applicator, pressure was applied to beads already deposited on the material samples by the method described above. The contaminated samples were placed onto a sample holder which was located on the center portion of a scale, the scale being rigidly mounted on a laboratory jack. The pressure could be controlled by reading the scale as the jack was elevated towards the rubber roller, which was fixed over the sample holder. When a reading of 50 lb was obtained, the sample was manually moved horizontally under the roller.

In an effort to maintain uniform electrostatic forces of the attraction of beads towards the sample material, tests were conducted while the room temperature was between 70 and 72°F and the relative humidity was between 50 and 60 %. Specific temperature and relative humidity could not be maintained, but by conducting all tests within these limits it was assumed that some standardization existed. The effect of the charge build-up from bead collisions and bead-to-material contact during all mechanical handling was not measured, nor was there any attempt to minimize the build-up. Each sample was handled in the same manner in an attempt to standardize any charge build-up effects.

DECONTAMINATION

Three simple removal operations were applied to the contaminated samples. (1) placing the sample in a vertical position; (2) applying 20 strokes of a camel hair brush; and (3) applying a 10-psi air jet until all macroscopically visible beads were removed. The removal operations were conducted in the sequence given above in all cases.

Each test run utilized one bead size group. Four samples of each material tested were used in each test run; of these one was not contaminated with beads and was used as a control to detect variation in weight relative to changes in room temperature and humidity. The remaining three samples were used to obtain the number of beads retained after each removal operation and to qualitatively determine the retention characteristics of the material.

Measurement of Residual Contamination

The amount retained by any sample before and after each removal operation was determined by two methods. When a relatively large

number of beads were visible on the sample, the amount deposited or retained was determined by differences in gross sample weight with an analytical balance, good to $\pm$ 0.0010 gram.

When little or no beads were macroscopically visible, and after the third removal operation, the amount retained was determined by examination of a preselected area of the sample by optical microscope. The preselected area was a circle (approximately 3.64 cm^2), situated in the center of the sample to eliminate edge effects. The area examined under the microscope was assumed to represent the entire sample. Based upon the quantity and size of beads retained within this area, a qualitative determination was made on the mechanism of retention.

The sizing was accomplished with an ocular micrometer containing a linear scale in the binocular microscope. A stage micrometer indicating 0.1 and 0.01 mm was selected as a standard to determine the linear scale division representations. For the ocular lens of 5x each scale division thus represented 30 μ, while for the 11x ocular lens each scale division represented 14 μ. Beads were generally sized to the nearest half scale division in terms of maximum diameter. All beads smaller than one half scale division were ignored. For the magnification utilized, glass beads less than one half scale division was not clearly distinguishable from a dust particle of the same size.

In obtaining the size distribution of the beads retained on any sample after each removal operation, at least 200 beads were sized *in situ*. For any one particular sample containing over 200 beads within the examined area of 3.64 cm^2, only the first 200 detected were sized and counted. The balance was counted without sizing.

Results obtained from measurements on the analytical balance and by microscope examinations were converted to a common unit (grams per square foot) for comparison. This unit would make feasible subsequent comparisons with the theoretical relationships of mass levels and ionization rates. Miller[5] used the relationship that approximately 30 g of radioactive weapon debris fallout per square foot produces an ionization rate of 1000 r/hr, at 3 ft above the ground and corrected to 1 hr after burst.

RESULTS AND DISCUSSION

Table 1 gives the results of the residual contamination before and after each decontamination operation for the 70M size group. It can be seen that greater than 98 % of the initial mass of beads applied by deposition were removed by the first removal process. This applied for all 9 clothing samples. The subsequent two operations increased the total removed to greater than 99 % for all the clothing samples.

Table 2 shows similar results for the 170M and 325M size groups. In Table 2, the weights removed after vertical positioning plus brushing are omitted since the percent of initial was less than 0.5 % in all cases. For these two groups, the mass remaining is generally higher than that for the 70M group.

The results for all the packaging materials except Scrim-back are shown in Table 3. The results for Scrim-back are listed separately in Table 4. In Table 3, the mass remaining after vertical positioning for some of the packaging materials are similar to clothing samples, but the subsequent removal operations reduces the amount remaining to essentially zero.

The results shown in Table 4 indicate that the mass of beads retained by Scrim-back is slightly greater than that by the clothing samples shown in Table 1.

Some of the packaging materials retained higher percentages after vertical positioning when compared to the average retained by cotton sateen cloth, but after the three successive removal operations these packaging materials retained zero amounts. Since the packaging materials which yielded these retention percentages did not possess any macroscopically visible retaining fibers, it must be assumed that an electrostatic force of retention was acting between the beads and the samples. The subsequent two removal operations overcame this force to remove practically all of the beads.

TABLE 1

Average of 70M Beads Retained on Cloths After Each Removal in Decontamination Sequence. Contamination by Deposition

Cloth	Initial Contamination (g/ft^2)	Weight After Removal					
		Vertical Positioning		Vertical Positioning and Brushing*		Vertical Positioning, Brushing, and Air Jet*	
		(g/ft^2)	(% of Initial)	(g/ft^2)	(% of Initial)	(g/ft^2)	(% of Initial)
C-1	114.9	1.84	1.60	0.0150	0.013	0.0096	0.0084
C-2	109.8	0.55	0.50	0.0211	0.019	0.0035	0.0032
C-3	135.4	2.30	1.70	0.0127	0.009	0.0020	0.0015
C-4	109.2	0.87	0.80	0.0085	0.007	0.0024	0.0022
C-5	122.6	0.86	0.70	-	-	0.0035	0.0029
C-6	118.1	0.94	0.80	0.0168	0.014	0.0012	0.0010
C-7	100.5	0.30	0.30	0.0030	0.002	0.0003	0.0003
C-8	127.1	0.38	0.30	0.0091	0.007	0.0002	0.0002
C-9	119.4	0.36	0.30	0.0029	0.002	0.0011	0.0009

*Number of beads per cm^2 converted to equivalent g/ft^2; 50 μ diameter and 2.5 g/cm^3 density assumed.

TABLE 2

Average of 170M and 325M Beads Retained on Cloths After First and Third Removals in Decontamination Sequence. Contamination by Deposition.

Cloth	Initial Contamination (g/ft^2)	Weight After Removal			
		Vertical Positioning		Vertical Positioning, Brushing, and Air Jet*	
		(g/ft^2)	(% of Initial)	(g/ft^2)	(% of Initial)
			170M		
C-1	103.6	1.66	1.60	0.0082	0.0079
C-2	121.0	0.73	0.60	0.0020	0.0017
C-3	126.2	4.67	3.70	0.0113	0.0090
C-4	126.3	1.64	1.30	0.0041	0.0032
C-5	122.2	1.83	1.50	0.0078	0.0064
C-6	125.8	10.6	8.43	0.0065	0.0052
C-7	122.1	1.10	0.90	0.0028	0.0023
C-8	124.4	0.75	0.60	0.0011	0.0009
C-9	128.1	2.30	1.80	0.0007	0.0005
			325M		
C-1	60.7	1.15	1.89	0.0164	0.0270
C-2	70.3	1.05	1.49	0.0174	0.0248
C-3	74.6	2.46	3.30	0.0423	0.0567
C-4	74.8	1.35	1.80	0.0254	0.0340
C-5	63.1	1.20	1.90	0.0248	0.0393
C-6	70.5	4.65	6.60	0.0810	0.1149
C-7	74.0	0.59	0.80	0.0100	0.0135
C-8	67.9	0.41	0.60	0.0048	0.0071
C-9	66.0	1.85	2.80	0.0237	0.0359

*Number of beads per cm^2 converted to equivalent g/ft^2; 50 μ diameter and 2.5 g/cm^3 density assumed.

TABLE 3

Average of 70M, 170M, and 325M Beads Retained on Packaging Materials, Except Scrim-back, After First and Third Removals in Decontamination Sequence. Contamination by Deposition.

Material	Initial Contamination (g/ft^2)	Weight After Removal			
		Vertical Positioning		Vertical Positioning, Brushing, and Air Jet*	
		(g/ft^2)	(% of Initial)	(g/ft^2)	(% of Initial)
		70M			
B-1	51.34	0.87	1.69	0.0004	0.0008
B-2	49.90	0.85	1.70	0.0002	0.0004
B-3	57.83	0.75	1.30	0.0002	0.0003
B-4	67.06	0.27	0.40	0.0004	0.0006
B-5	63.60	0.19	0.30	0.0002	0.0003
B-6	66.34	0.04	0.06	0.0002	0.0003
B-7	66.63	0.20	0.30	0.0001	0.0002
B-8	55.52	0.22	0.40	0.0000	0.0000
B-9	53.94	0.22	0.41	0.0000	0.0000
B-10	53.07	0.05	0.09	0.0000	0.0000
A-6	7.93	0.16	2.02	0.0000	0.0000
A-7	15.72	0.66	4.20	0.0000	0.0000
A-8	9.66	0.09	0.93	0.0000	0.0000
F-7	42.11	2.15	5.11	0.0000	0.0000
		170M			
B-1	86.41	2.16	2.50	0.0000	0.0000
B-2	93.87	3.19	3.40	0.0003	0.0003
B-3	92.10	1.20	1.30	0.0003	0.0003
B-4	107.98	1.09	1.00	0.0006	0.0006
B-5	100.65	0.20	0.20	0.0003	0.0003
B-6	78.54	0.03	0.04	0.0001	0.0001
B-7	83.97	0.17	0.20	0.0001	0.0001
B-8	72.57	0.22	0.30	0.0000	0.0000
B-9	60.63	0.61	1.01	0.0000	0.0000
B-10	72.71	0.01	0.01	0.0000	0.0000
A-6	79.49	0.16	0.20	0.0000	0.0000
A-7	71.89	7.05	9.81	0.0000	0.0000
A-8	69.45	0.14	0.20	0.0000	0.0000
F-7	83.15	3.49	4.20	0.0000	0.0000

Continued

TABLE 3 (contd)

Average of 70M, 170M, and 325M Beads Retained on Packaging Materials, Except Scrim-back, After First and Third Removals in Decontamination Sequence. Contamination by Deposition.

Material	Initial Contamination (g/ft^2)	Weight After Removal			
		Vertical Positioning		Vertical Positioning, Brushing, and Air Jet*	
		(g/ft^2)	(% of Initial)	(g/ft^2)	(% of Initial)
		325M			
B-1	50.85	2.03	3.99	0.0020	0.0039
B-2	55.87	4.30	7.70	0.0000	0.0000
B-3	54.28	1.79	3.30	0.0000	0.0000
B-4	56.27	1.24	2.20	0.0049	0.0087
B-5	54.84	0.16	0.29	0.0041	0.0075
B-6	59.94	0.36	0.60	0.0001	0.0002
B-7	59.70	5.19	8.69	0.0036	0.0060
B-8	52.45	0.21	0.40	0.0000	0.0000
B-9	58.42	0.47	0.80	0.0000	0.0000
B-10	53.80	0.32	0.59	0.0000	0.0000
A-6	64.48	0.13	0.20	0.0000	0.0000
A-7	51.09	3.78	7.40	0.0000	0.0000
A-8	66.71	0.13	0.19	0.0000	0.0000
F-7	62.09	0.75	1.21	0.0002	0.0003

*Number of beads per cm^2 converted to equivalent g/ft^2; 50 μ diameter and 2.5 g/cm^3 density assumed.

TABLE 4

Average of 70M, 170M and 325M Beads Retained on Scrim-Back Packaging Material After Each Removal in Decontamination Sequence. Contamination by Deposition.

Bead Group	Initial Contamination (g/ft^2)	Weight After Removal: Vertical Positioning (g/ft^2)	Vertical Positioning (% of Initial)	Vertical Positioning and Brushing* (g/ft^2)	Vertical Positioning and Brushing* (% of Initial)	Vertical Positioning, Brushing, and Air Jet* (g/ft^2)	Vertical Positioning, Brushing, and Air Jet* (% of Initial)
70M	65.04	1.17	1.80	0.0015	0.0023	0.0008	0.0012
170M	87.63	3.07	3.50	0.3107	0.3546	0.0622	0.0710
325M	66.47	3.59	5.40	-	-	0.2812	0.4230

*Number of beads per cm^2 converted to equivalent g/ft^2; 50 μ diameter and 2.5 g/cm^3 density assumed.

Beads retained after each removal operation were microscopically examined and sized. Figure 2 shows a size distribution of beads retained by the untreated cotton sateen cloth. The number of beads retained decreased with each removal operation and the percentage of the number of larger size beads decreased with each operation. Similar results were indicated on all other clothing and Scrim-back samples.

Macroscopic surface examinations of all materials tested revealed that all packaging materials except Scrim-back were smooth. All cloth and Scrim-back samples were identified as fibrous. Comparison of the amounts of beads retained with degree of fibrousness revealed a direct proportional relationship. Materials with smooth surfaces retained insignificant amounts after the three removal operations, whereas Scrim-back packaging material, which had the largest inter-yarn spaces and the most protruding tentacles, had the highest number retained. Fig. 3, which shows beads being retained on Scrim-back, reveals the large spaces between yarns and the many tentacles. It also shows the tentacles holding the beads.

Table 5 shows the effect of direct transfer on bead retention by clothing material. Results are given as ratios of the mass retained after the three removal operations, for samples contaminated by direct transfer to those by deposition. It can be seen that the pressure applied has forced the particles into the fibers and caused higher residual contamination.

Although analyses of the relative merits of the treatments on cloth samples with respect to residual contamination characteristics was beyond the scope of the test, results obtained for the deposition method indicate some variations due to the treated surfaces. In general, the treated cotton sateen samples retained smaller mass of beads compared to the untreated cotton sateen. A comparable effect on the cotton poplin was not evident.

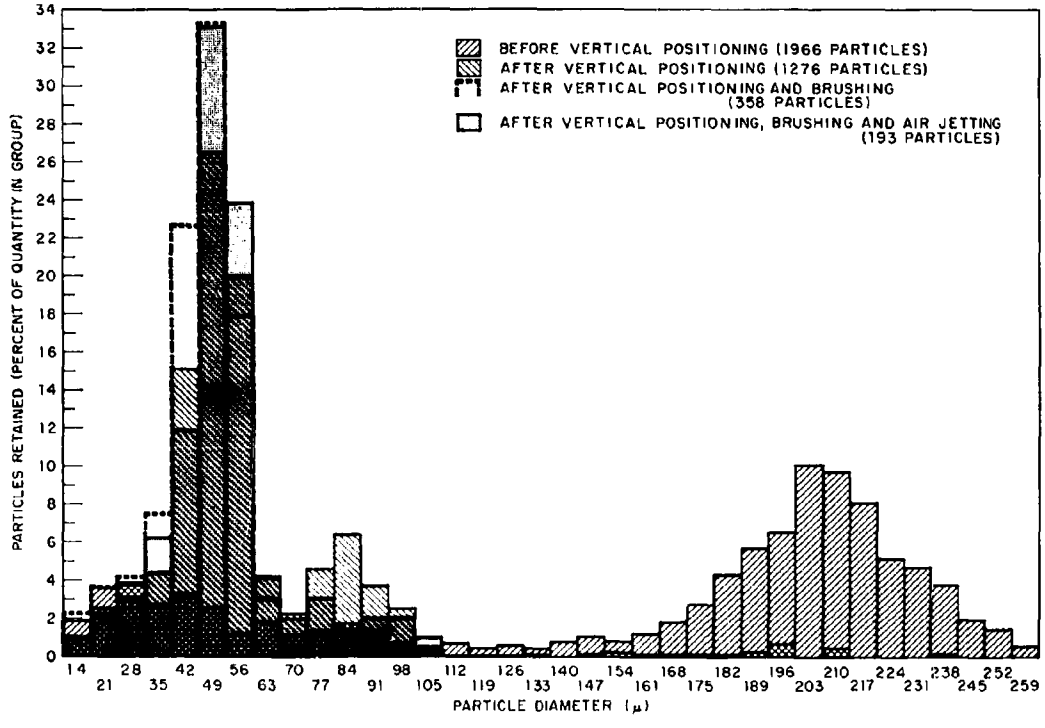

Fig. 2 Size Distribution of 70M Particles on Untreated Cotton Sateen Cloth (C-1), Before and After Three Removals in Decontamination Sequence.

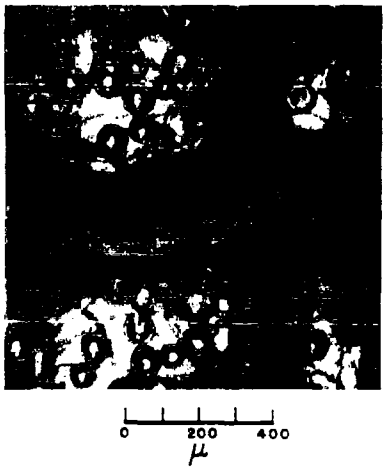

Fig. 3 Particles Retained on Scrim-Back (F-6) Packaging Material.

TABLE 5

Comparison of Residual Contamination on Clothing Material After Decontamination Sequence, Following Deposition and Direct Transfer Methods of Impingement.

Cloth	Residual Contamination					
	70M			170M		
	Deposition (g/ft^2)	Direct Transfer (g/ft^2)	Ratio: Direct Transfer/ Deposition	Deposition (g/ft^2)	Direct Transfer (g/ft^2)	Ratio: Direct Transfer/ Deposition
C-1	0.0096	0.0130	1.35	0.0082	0.0396	4.83
C-2	0.0035	0.0085	2.43	0.0020	0.0154	7.70
C-3	0.0020	0.0083	4.15	0.0113	0.0425	3.76
C-4	0.0024	0.0040	1.67	0.0041	0.0210	5.12
C-5	0.0035	0.0065	1.86	0.0078	0.0353	4.53
C-6	0.0012	0.0124	10.3	0.0065	0.0254	3.91
C-7	0.0003	0.0018	6.00	0.0028	0.0216	7.71
C-8	0.0002	0.0005	2.50	0.0011	0.0155	14.1
C-9	0.0011	0.0015	1.36	0.0007	0.0109	15.6

Note: Number of beads per cm^2 converted to equivalent g/ft^2; 50 μ diameter and 2.5 g/cm^3 density assumed.

CONCLUSIONS AND RECOMMENDATIONS

The packaging materials, except Scrim-back, presented little or no residual contamination after three successive removal operations. In those cases where an electrostatic force held beads to the surface after vertical positioning, the more vigorous methods, brushing and air jetting, removed the beads easily.

Scrim-back and all cloth samples, which have spaces between yarns and many fibers acting as mechanical traps, retained detectable amounts of glass beads even after three successive removal operations. Scrim-back retained more beads than cloth samples. Cotton sateen cloth, treated and untreated, retained slightly more than the cotton poplin cloth, treated and untreated.

In general, particles of the shape and size of the test beads which impinge by deposition or by direct transfer onto such materials as those tested are held by a mechanical bond (no bonding). Methods of removal slightly more vigorous than vertical positioning easily overcome this bond. Particles retained after the three removal operations used can probably be removed easily by other means such as vacuuming or laundering. Field expediencies of particle removal will probably suffice to remove 98 % of the particles. The variation of shape in the test particles would unquestionably increase the amounts retained by the samples studied. In this test, however, the effect of shape was idealized by utilizing spherical particles only.

Undoubtedly, particles of diameter less than the 14 μ used would have been more difficult to remove by the mechanical particle removal methods utilized. The particles are held wire-like by the fibers. Even though the residual contamination will be much higher when small particles are present, the radiation levels produced will probably be lower or insignificant. Data from past weapons effects tests indicate that particles less than 15 μ produced the lower radiation readings.

No attempt was made to correlate test results with radioactive fallout particles which arise from nuclear detonations. Such variables

as particle size distribution with distance, specific activity per particle, location of radioactivity within the particle, shape, density, chemical composition, mass levels produced, solubility, and magnetic properties all complicate the problem. Through postulating or assuming specific values for the many variables, these test results probably could be correlated with fallout data, similarly to the calculations performed by Clark.* This was not done in this study since the retention characteristics of various QMC materials was of primary interest. However, a rough indication can be made of the significance of the initial mass levels employed through the relation: approximately 30 g of radioactive weapon debris fallout/ft^2 produces an ionization rate of 1000 r/hr, 3 ft above the ground and corrected to 1 hr after burst.[5] Thus the maximum mass levels employed in the experiment, approximately 130 g/ft^2, correspond to a standard field intensity of about 4000 r/hr at 1 hr.

Simpler detection and measurement techniques such as use of radioactively tagged particles of a known size distribution, shape, and activity level, should be investigated further. In any future test, the physical and chemical characteristics of fallout particles as functions of burst environment, yield, and distance from ground zero, should be carefully examined so that the fallout simulant may be more vigorously associated with any desired radiological situation.

Since this study did not include the effects of humidity, oil bonding, shape of particles, and electrostatic forces of particle retention on clothing materials, any further investigation should include these effects.

*D. E. Clark, private communication.

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2. Packaging - Effects of radiation.
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It was found that materials having entrapping fibers retained the largest amount of beads. The amount was directly proportional to the number of open spaces and the number of loose fibers that acted as entrappers. Scrim-back packaging material measured 0.3 g/ft^2 of particles which had an average diameter of 50 μ. Cotton sateen clothing and cotton poplin clothing had lesser amounts. All other materials tested retained zero or insignificant amounts.

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